Investigation of In-Stream Construction-Induced Suspended Sediment in Riverine Ecosystems

Report

NSERC Engage Grant

In Partnership with

DFH Enterprises Inc.

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Summary
DFH Enterprises Inc. (DFH) partnered with researchers at the University of British Columbia to undertake an investigation of in-stream construction-induced suspended sediment (ICISS) to better understand the characteristics of temporary, point-source sediment releases resulting from construction activities and their impacts on riverine ecosystems. This study was accomplished through a literature review of relevant topics to determine possible ICISS exposure risk mechanisms and a field monitoring program to verify theoretical exposure risk mechanisms, which was conducted during in-stream construction activities undertaken through the Policeman’s Flats River Hazard Removal (PFRHR) Project commissioned by the Bow River Trout Foundation (BRTF).

The water quality data analyzed from the PFRHR Project indicates that the in-stream construction activities resulted in ICISS exposure risks that were well below the threshold recommended by the Canadian Council of Ministers of the Environment (CCME) Water Quality Guidelines for the Protection of Aquatic Life (CCME, 2002). Therefore, it is likely that the Bow River ecosystem was sufficiently protected and no adverse environmental effects resulted from the activities undertaken. The following table summarizes the ICISS exposure risk resulting from the PFRHR activities.

<table>
<thead>
<tr>
<th>Hazard Removal</th>
<th>Non-Isolated Experiment</th>
<th>Isolated Experiment</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.42</td>
<td>2.70</td>
<td>3.53</td>
<td>4.07</td>
</tr>
</tbody>
</table>


The PFRHR Project activities indicated that attempting to control suspended sediment concentration through the installation of hydraulic and sediment isolation structures was not effective for the Project’s scope of activities and resulted in greater ecosystem exposure risk than conducting the same activities without isolation. Although increases to suspended sediment concentration were observed during the non-isolated experimental activity, when compared to the isolated experimental activity, the increased scope and duration of in-stream construction activities to install the isolation structures were more influential on calculated exposure risk. This finding must be considered within the context of the specific scope of in-stream construction activities for the given project. Further research is required to determine the validity of the findings of this study more generally.
1 Introduction
DFH Enterprises Inc. (DFH) and the Bow River Trout Foundation (BRTF) partnered with researchers at the University of British Columbia to undertake an investigation of in-stream construction-induced suspended sediment (ICISS) to better understand the characteristics of temporary, point-source sediment releases resulting from construction activities within the context of impacts to riverine ecosystems. The goal of the research was to identify and explore the mechanisms in which construction activities may cause suspended sediment exposure risks to riverine ecosystems and provide recommendations to reduce ICISS impacts. This work was completed under an NSERC Engage grant in partnership with DFH, along with support provided by BRTF to commission a portion of the construction activities and donation of research equipment.

The study involved two components: (1) a review of existing construction and care of water practices, environmental regulatory guidelines, ICISS exposure mechanisms within river systems, and suspended sediment effects on fish and fish habitat, and (2) a field monitoring program conducted on April 18, 2018 during the Policeman’s Flats River Hazard Removal (PFRHR) Project to characterize sediment releases and quantify ICISS exposure risks on a project which consisted of disruptions to river substrates, causing temporary, point-source suspended sediment releases.

2 Literature Review
This study reviewed the existing construction and care of water practices, environmental regulatory guidelines, sediment exposure mechanisms within river systems, and suspended sediment effects on fish and fish habitat.

2.1 Construction and Care of Water Practices
In-stream construction is generally comprised of heavy equipment interacting with a river system either directly or indirectly based on the scope of construction activities. Direct interactions will occur when equipment such as an excavator or other machine must enter the wetted perimeter of the watercourse to conduct construction activities. The scope of work may include constructing hydraulic and/or sediment isolations, dredging, material placement, or other activities which require work in a river (Cocchiglia et al., 2012). Indirect interactions will occur when equipment is either working upslope of the wetted perimeter of the watercourse or working within a hydraulic and/or sediment control isolation (Chapman et al., 2014). Generally, these direct or indirect interactions have the potential to cause the release of suspended sediment through the disruption of streambed substrate or other soils.

Hydraulic and/or sediment isolation measures may be constructed with a combination of riprap, gravel, geotextiles, or other material to provide a hydraulic or sediment barrier between the disruptive construction activities and the flow of the channel (Chapman et al., 2014). There is limited published literature on the effectiveness of these measures to protect riverine ecosystems from harmful effects resulting from in-stream construction activities.

2.2 Suspended Sediment Exposure Mechanisms
Suspended sediment may be released into the environment from construction activities that disturb natural sediments, which then become suspended in flow. This can be caused by
activities such as movement of equipment, excavation of streambed, or placement of materials within the wetted perimeter of the channel. Adjacent activities upslope of the wetted perimeter of the channel may also contribute to suspended sediment releases if insufficient erosion control measures are implemented (Chapman et al., 2014).

2.3 Suspended Sediment Effects on Fish and Fish Habitat

ICISS effects on fish and fish habitat result from the combination of concentration, duration and spatial extents. Newcombe and Jensen (1996) conducted a meta-analysis of literature related to suspended sediment effects on fish and fish habitat and developed organism-specific concentration-duration relationships to predict severity of ill-effects (SEV) scores and corresponding adverse effects. These scores range from 0-14, corresponding to behavioural to lethal effects, as well as habitat degradation impacts. The organism-specific relationships were developed as multi-parameter logarithmic expressions as shown in Equation 1.

\[ SEV = a + b(\ln(t)) + c(\ln(C)) \]

Where, \( a, b, c \) are organism-specific empirical coefficients and \( t \) and \( C \) are duration (hours) and suspended sediment concentration (mg/L), respectively.

2.4 Environmental Regulatory Guidelines

The current environmental regulatory guidelines within the province of Alberta, as developed and applied by Alberta Environment and Parks (AEP), focus on limiting suspended sediment concentrations. Although project-specific requirements may vary, the prevailing requirement in the South Saskatchewan Management Region in Alberta has implemented a turbidity exceedance threshold of 8 NTU or 25 mg/L above background levels, regardless of construction duration (Alberta Government, 2017).

The underlying literature with which environmental guidelines are developed is based on the Canadian Council of Ministers of the Environment (CCME) Water Quality Guidelines for the Protection of Aquatic Life and suggests a short-term exposure dosage limit of 25 mg/L over a 24 hour duration (CCME, 2002). This exposure limit was derived from Newcombe and Jensen (1996), which indicates that suspended sediment exposure risk is a function of concentration and duration, and notes that concentration alone is a poor indicator of exposure effects. Additionally, Courtice and Naser (in review) suggests that spatial extents of exposure should also be taken into consideration due to the complex ICISS plume characteristics and the spatial variability that results in suspended sediment concentration gradients downstream of the ICISS release point.

Thus, the existing regulatory guidelines do not sufficiently consider all aspects of ICISS exposure risk, indicating there is room for improvement in the approaches to manage and execute in-stream construction projects.

3 Field Study

The Policeman’s Flats River Hazard Removal (PFRHR) Project was commissioned by the Bow River Trout Foundation (BRTF) to remove flood debris adjacent to the Policeman’s Flats river access point south of Calgary, Alberta on the Bow River. The flood debris, primarily large riprap boulders, had accumulated on the streambed from recent low-probability flood events,
creating river hazards for boaters attempting to use the river access point at Policeman’s Flats. The project consisted of indirect (parking lot and boat launch grading) and direct (debris removal) interactions with the river. The field study investigated the direct interactions with the Bow River.

**Experimental In-Stream Construction Activities**

In addition to the river hazard removal activities, experimental in-stream construction activities were conducted to investigate the efficacy of attempting to control suspended sediment releases within the wetted perimeter of the river. Two 5 m² study zones of the river, located side by side, were each exposed to a 3m³ excavation, followed by the placement, then removal of riprap, and finally replacement of the previously excavated gravels. The first study zone maintained full interaction with the river, without implementing hydraulic or sediment control measures. The second study zone had a traditional lock-block style isolation installed prior to conducting the experimental activities. The first study zone activity was completed in full prior to commencing the second study zone activity to ensure suspended sediment releases from each activity could be attributed to their respective activity.

**Suspended Sediment Monitoring**

Suspended sediment was monitored using optical turbidity sensors, in-situ samples, unmanned aerial vehicle (UAV) video and photo documentation, and visual observations.

Six optical turbidity sensors (two Campbell Scientific OBS-3+ and four Campbell Scientific OBS units), measuring turbidity in nephelometric turbidity units (NTU) every twenty seconds, were deployed between two monitoring zones (Figure 1). The first monitoring zone was located approximately one river-width (50 m) downstream of the construction activities, where three sensors were deployed longitudinally at approximately 20 m spacing. The second monitoring zone was located approximately eight river-widths (400 m) downstream of the construction activities, where three sensors were deployed across the width of the river at approximately 10 m spacing. Exact deployment locations were highly dependent on the feasibility of maintaining a stable deployment location for the sensors, which was a function of flow depth, velocity, and substrate characteristics.

In-situ samples (N=102) were collected at the six turbidity sensor locations, one specified location approximately 1 km downstream of the construction activities, twelve randomly selected locations within the study reach, and a baseline sampling location upstream of the activities. Samples were collated by location and analyzed to determine anticipated exposure risks at each location based on the average concentration exhibited at the site and the documented activity duration. Severity of Ill-Effect (SEV) scores were calculated using the Newcombe and Jensen (1996) concentration-duration relationship for adult and juvenile salmonids. This relationship was used in CCME (2002) to derive suspended sediment concentration thresholds for the protection of aquatic life, however for the purposes of determining relative exposure risk compared to background suspended sediment levels, any of the published relationships would be suitable. SEV scores calculated from field data were compared with CCME (2002) guidelines to determine the likelihood of adverse effects resulting from the ICISS releases observed during construction activities.
Exposure risk was calculated for each unique activity and compared to investigate the mechanisms present during in-stream construction activities that most influence exposure risk.

![Activity Location](image)

**Figure 1:** Sampling locations in relation to the activity location. Orthophoto courtesy of Airborne Engineering Corporation.

### 4 Results

The in-stream construction activities undertaken during the PFRHR project were completed in 5 hours and observed an average concentration over the affected habitat within the study reach of approximately 21 mg/L, with a maximum concentration of 128 mg/L. The plume was visually observed as far downstream as the second monitoring zone at 400 m downstream of the construction activities, however heightened concentrations were measured at all monitoring locations within the study reach. Thus, the identified plume extents were separated into “observable plume extents” and “estimated extended plume extents” as presented in **Figure 2**.

The total plume extents created an exposure risk SEV score of 4.28, which was an increase of 0.32 above the background SEV score of 3.96 calculated based on background suspended sediment concentrations observed upstream of the activities over the duration of construction. The total habitat area within the study reach affected by the plume was approximately 77%, with an average SEV increase from 3.96 to 4.07.

The SSC measurements presented in **Figure 3** indicate that at the first monitoring zone, large variability and substantially heightened concentrations (9.5-127.5 mg/L) were observed, whereas the second monitoring zone exhibited more uniform concentrations (9.5-23.5 mg/L) that were only slightly higher than the average background concentration of 13.5 mg/L. Turbidity sensor data was highly variable due to variability in suspended particle characteristics and suspended debris such as weeds that had the potential to become periodically caught within the sensor sampling volume. Two of the sensors (T11 and T22) did not provide usable data while the other four sensors provided additional turbidity data to enhance the information collected from in-situ samples. The sensor data is presented in **Appendix A**.
Figure 2: Extents of study reach habitat and estimated plume extents based on monitoring results and observations. Imagery taken from Google Earth™.

Table 1 and 2 present the activity-specific and location-specific exposure risk for each, based on the suspended sediment concentration (SSC) measurements presented in Figure 3 and the corresponding duration of each activity. All activities fall well below the SEV score threshold of 5.37 established by CCME (2002) guidelines for the protection of aquatic life. Turbidity sensor data were not used to calculate exposure risk due to high variability in correlation between the measured parameter (turbidity) and parameter of interest (suspended sediment concentration). A possible explanation for this is due to the high variability of suspended particle characteristics, which include organic material in addition to sediment. As a result the relationship between turbidity and suspended sediment is not as strong as the theoretical relationships developed when considering homogenous suspended particles consisting solely of suspended sediment.

Table 1: Activity-specific exposure risk (SEV Score) within study reach based on in-situ suspended sediment samples.

<table>
<thead>
<tr>
<th>Hazard Removal (1.5 Hours)</th>
<th>No Isolation (0.5 Hours)</th>
<th>Isolation (2.2 Hours)</th>
<th>Total (5 Hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.42</td>
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<td>3.53</td>
<td>4.07</td>
</tr>
</tbody>
</table>
Table 2: Location-specific exposure risk (SEV Score) based on in-situ suspended sediment samples.

<table>
<thead>
<tr>
<th>Location</th>
<th>Hazard Removal (1.5 Hours)</th>
<th>No Isolation (0.5 Hours)</th>
<th>Isolation (2.2 Hours)</th>
<th>Total (5 Hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T11/T12/T13</td>
<td>3.82</td>
<td>3.13</td>
<td>3.91</td>
<td>4.53</td>
</tr>
<tr>
<td>T21/T22/T23</td>
<td>3.43</td>
<td>2.66</td>
<td>3.53</td>
<td>4.11</td>
</tr>
<tr>
<td>1 km</td>
<td>3.46</td>
<td>2.34</td>
<td>3.54</td>
<td>4.03</td>
</tr>
<tr>
<td>Baseline</td>
<td>3.24</td>
<td>3.21</td>
<td>3.45</td>
<td>3.96</td>
</tr>
</tbody>
</table>

Comparing the two experimental activities, the non-isolated activity resulted in the highest measured concentrations, however had a duration of 0.5 hours as opposed to the isolated activity’s 2.2 hour duration. This increased duration resulted from the time required to construct the lock-block isolation in an attempt to control sediment and reduce sediment-entraining velocities in the workspace. Overall, the non-isolated activity resulted in a lower exposure risk due to the minimal increase in average concentration and substantial decrease in duration.
**Figure 3:** In-situ suspended sediment concentration (SSC) samples taken at locations T11/T12/T13 and T21/T22/T23 throughout the duration of hazard removal activities (1), non-isolated experimental activities (2), and isolated experimental activities (3).

**4 Discussion**

The current regulatory requirements in the South Saskatchewan Management Region, which includes the Bow River, result in a narrow management approach where in-stream construction is managed through an effort to control sediment releases, while no consideration is given to duration or spatial extents of exposure. When comparing similar activities through the inclusion or omission of suspended sediment control measures, duration appears to have a larger response to isolation implementation, and thus a more influential exposure risk mechanism, than concentration. The discrete SSC measurements that were substantially in exceedance of the prevalent 25 mg/L regulatory threshold, did not appear to have substantial impacts on the overall exposure risk SEV score found within the study reach,
as the overall exposure risk increased from 3.96 to 4.07. This indicates that the localized increases in SSC do not have a large effect on exposure risk when the spatial extents of exposure risk are considered.

When investigating the experimental activities, the hydraulic and sediment control measures did not perform effectively when attempting to establish an isolation around the worksite. This result was likely due to the irregularity and permeability of streambed characteristics. It is challenging to create a perfect hydraulic and sediment isolation without uniform bed characteristics. For the duration that a perfect isolation is not present during in-stream construction activities, sediment will be released into the river. Additionally, the freshly disrupted sediment within the isolation is released upon exposure to heightened flow velocities once the isolation is removed. The measured sediment concentrations downstream of the activities were reduced during construction resulting from the isolation measures, however the increased duration of construction negated the benefit of attempting to control sediment releases.

Considering the relatively short activity duration in relation to the scope of sediment control measures, the results do not definitively conclude whether or not sediment control measures are applicable to all in-stream construction projects. Rather, the results indicate that a pragmatic approach should be considered on a project-specific basis. Suspended sediment control measures are likely beneficial for projects where they may be constructed very quickly in relation to the anticipated total in-stream construction duration. For projects where sediment control measures will substantially extend the duration of construction, suspended sediment control measures should be carefully considered and potentially avoided if deemed pragmatic for conditions present. In the event no sediment control measures are implemented, alternative environmental protection measures should be considered, if deemed necessary, to address any outstanding environmental risks identified through a proposed project’s environmental impact assessments. For example, if there is an identified risk of directly harming fish through the construction activities, a block net or other fish isolation structure which does not disrupt streambed substrates should be considered to ensure fish remain outside construction extents. Further research is required to better understand the role of suspended sediment control measures in reducing or increasing ICISS exposure risk as a function of project scope to provide comprehensive recommendations.

5 Conclusion

The Policeman’s Flats River Hazard Removal (PFRHR) Project consisted of in-stream construction activities, exhibiting in-stream construction-induced suspended sediment (ICISS) releases. These sediment releases were documented through in-situ measurements and turbidity sensors, which collected data at various locations downstream of the activities. All activities resulted in exposure risks that are within accepted levels as determined by CCME (2002).

The results from this research indicate that it is important to consider the duration, anticipated suspended sediment concentrations, and scope of in-stream construction activities to pragmatically determine the best approach to complete in-stream construction activities for the reduction of ICISS exposure risks. It is challenging to reduce ICISS exposure risks through sediment control measures without substantially increasing the scope of in-stream construction activities, which in turn may lead to a counterproductive increase in
ICISS exposure risk due to an extended period of in-stream construction activities. Thus, it is important to consider the efficacy of sediment control measures in the context of reducing overall ICISS exposure risk and consider whether an equal or greater protection of aquatic life may be implemented through managing construction duration. This assessment should be conducted by a qualified aquatic environmental specialist (QAES) by considering and comparing the impact and scope of sediment control measures in relation to the impact and scope of project activities. For cases where the project scope is much larger in magnitude to applicable sediment control measures, it is likely that the measures are warranted, whereas if the project scope is of similar magnitude to applicable sediment control measures, it is possible that these measures may increase project impacts.

References
Courtice, G. and Naser, B. (in review). In-Stream Construction-Induced Suspended Sediment in Riverine Ecosystems. River Research and Applications in review.
Photos:

Photo 1: Aerial image of the localized plume within the vicinity of the activities and the first monitoring zone (T1/T2/T3). Photo courtesy Airborne Engineering Corporation.
Photo 2: Aerial image of the activity location and plume characteristics. The plume split between the main flow and the backwater area prior to reconnecting downstream of the silt curtain. Photo courtesy Airborne Engineering Corporation.
Photo 3: Constructing the lock block isolation prior to conducting the isolated experimental activities. A silt curtain was also installed within the internal perimeter of the lock block structure to provide additional sediment control. As depicted in the photo, it was difficult to align each block to create a fully impermeable isolation due to streambed irregularities, a common challenge for river construction projects.
Appendix A - Turbidity Sensor Data

Figure A1: Campbell Scientific OBS optical turbidity sensor located at T12 and corresponding in-situ suspended sediment concentration (SSC) samples. Sensor data was correlated to SSC through field and laboratory calibration techniques. There is substantial noise in the data, however the in-situ measurements show reasonably consistent results indicating the general trend recorded by the sensor is likely reflective of sediment plume characteristics. Exposure risk values were not calculated using this data due to its noise and variance from in-situ measurements.
Figure A2: Campbell Scientific OBS-3+ optical turbidity sensor located at T13 and corresponding in-situ suspended sediment concentration (SSC) samples. Sensor data was correlated to SSC through field and laboratory calibration techniques. The in-situ measurements show reasonably consistent results indicating the general trend recorded by the sensor is likely reflective of sediment plume characteristics. Exposure risk values were not calculated using this data due to its noise and variance from in-situ measurements.
Figure A3: Campbell Scientific OBS-3+ optical turbidity sensor located at T21 and corresponding in-situ suspended sediment concentration (SSC) samples. Sensor data was correlated to SSC through field and laboratory calibration techniques. The in-situ measurements show reasonably consistent results indicating the general trend recorded by the sensor is likely reflective of sediment plume characteristics. The large spike at hour five is attributed to the removal of the silt curtain which released a substantial amount of silt that had accumulated during construction activities. Visual observations indicated that this release was confined very closely to the streambank and moved through a flow path that did not intersect other sensors. As this activity was not of interest for the research activities, it was not included in the data analysis. Exposure risk values were not calculated using this data due to its noise and variance from in-situ measurements.
Figure A4: Campbell Scientific OBS optical turbidity sensor located at T23 and corresponding in-situ suspended sediment concentration (SSC) samples. Sensor data was correlated to SSC through field and laboratory calibration techniques. There is substantial noise in the data and in-situ measurements do not reflect the heightened turbidity measurements recorded, however the general trend is similar to other sensors, thus the data is likely representative of the general trends observed. Exposure risk values were not calculated using this data due to its noise and variance from in-situ measurements.